1up

HIGH WIND POWER PLANTS

H. Honnef

(NASA-TT-F-15444) HIGH WIND POWER PLANTS (Scientific Translation Service) ~~19~~ 18 p HC CSCL 10A
N74-19709
Unclas
G3/03 34391

Translation of "Höhenwindkraftwerke", Elektrotechnik und Maschinenbau, Vol. 57, No. 41 and 42, October 13, 1939, pp. 501 - 506.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 APRIL 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,444	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle High Wind Power Plants		5. Report Date April, 1974
		6. Performing Organization Code
7. Author(s) H. Honnef		8. Performing Organization Report No.
		10. Work Unit No.
		11. Contract or Grant No. NASw-2483
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Höhenwindkraftwerke", Elektrotechnik und Maschinenbau, Vol. 57, Nos. 41 and 42, October 13, 1939, pp. 501 - 506.

16. Abstract

In comparison to the usual power plants in which the machines are installed in special buildings, the high wind power plant is described as a power source in which the structure as a whole makes up the machine. New large structures are supports for generators with large diameters but with the other dimensions small. The use of the advantageous high wind flow leads to unusually high structures, but these are completely storm-safe and stable, as well as economical. Details of the counter-rotating turbine and some experimental results are presented.

17. Key Words (Selected by Author(s))		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 17	22. Price

HIGH WIND POWER PLANTS

H. Honnef

A. The Course of the Wind /501*

High wind power plants are different from windmills and the well-known single turbines. Several large turbines are combined high above the ground, but so that the lowest edges of the wings are still more than 100 m above the ground. The large turbines are intended to work in the high zone, and to be removed from the disturbances of the surface turbulence zone.

We must differentiate between the two zones in evaluating the wind. Valuable measurements about the course of the wind have become known through the investigations of the well-known meteorologists, Assmann [1] and Hellmann [2]. Although Assmann was the first to work up the results from 20 to 30 years of measurements at German Weather Service stations, Hellmann was the first to establish the course of the high wind. The measurements by Hellmann were confirmed by the meteorologists Pilgrim (Stuttgart), Grosse (Bremen), Bradtke, Laske, and H. Bongards, who also set up new formulas for the increase of wind velocity with height. The formula values are supported by measurements at Nauen and Potsdam. Later measurements in other regions showed greater wind speeds in the high zone than were established by Hellmann, among others. Testing of the numbers, with changing of the wind speeds by means of the publications of the "Aerodynamic Reports" of the Flight Weather Service yielded higher values [3]. Also, the 30,000 test measurements done in recent years by the Reich Weather Service has improved the first results.

* Numbers in margin indicate pagination in original foreign text.

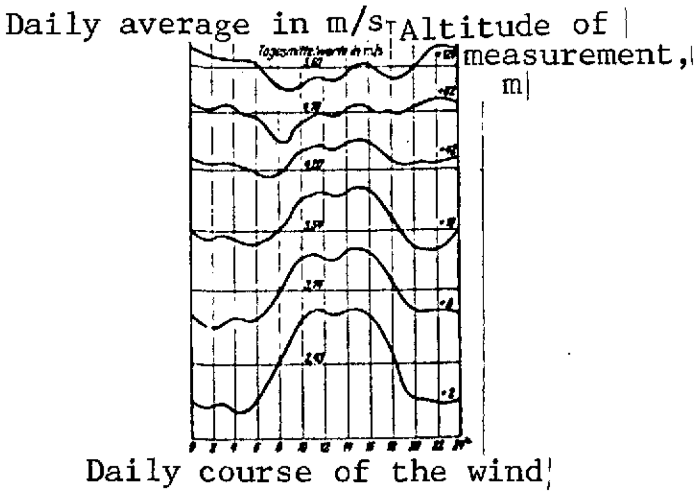

Figure 1. Averages of the daily course of the wind speed at different altitudes

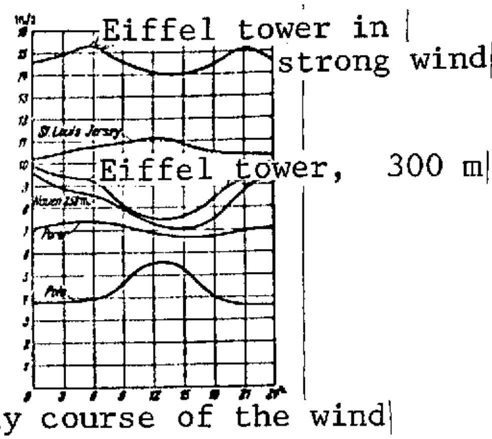

Figure 2. Averages of the daily course of the wind speed for some locations

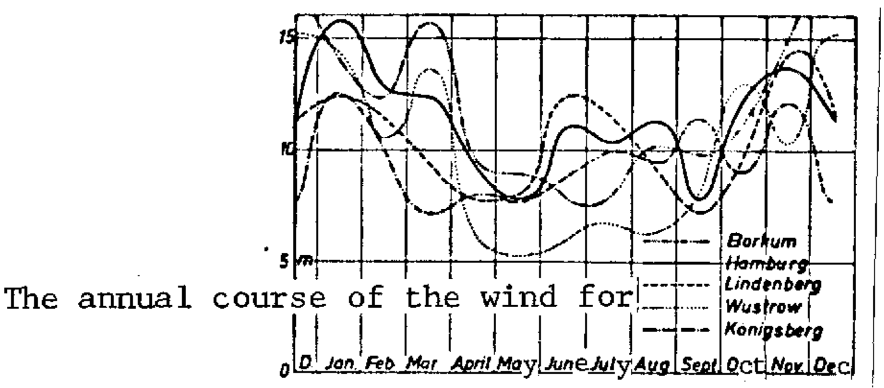

Figure 3. Averages of the yearly course of the wind speed for some locations

In the surface turbulence zone, the average annual velocity has been established as 5 to 6 m/s. This doubles in the high zone. The daily course also changes. Figure 1 shows the change with altitude for zones from 2 meters above the ground up to 124 m. While there are still considerable fluctuations in the lower zones, with the strongest deviations at noon, the daily course becomes more even with increasing altitude. At about 100 m above the ground, the noon amplitude disappears. At higher altitude, 300 m, the yearly average shows a weak depression in the daily course, which is almost compensated with strong winds. The power of the wind increases with v^2, and is therefore eight times stronger in the high zone with doubled wind speed than in the surface turbulence zone. This eight-fold power is combined with greater evenness in the yearly average. More compensation is possible if the major wind regions are connected with each other. Maximum and minimum powers never occur simultaneously in all regions. Figure 2 shows the daily course of the winds for /502 some locations, and Figure 3 shows the yearly course for different wind regions of Germany, and the differences existing between the individual regions at the same time. If one balances out the fluctuations at the same time, then one obtains very high uniformity, which can be improved even more by selection of regions matched to each other. Practically, compensation is possible by means of collecting lines and ring mains. According to Figure 3 it is possible to limit the fluctuations in the yearly power to some 4% if the matched wind regions are connected together.

B. Conversion of the Wind Energy into Electricity in Present Turbines

The stagnation pressure of the wind in front of the turbine generates the wheel thrust

$$H = 1/18 \cdot v^2 \cdot f$$

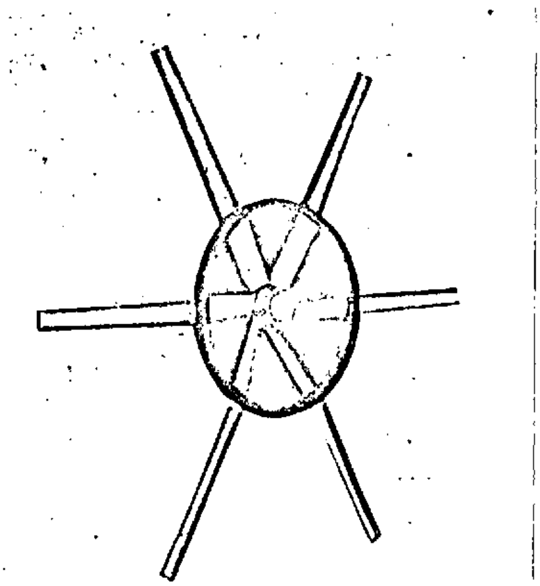

Figure 4. Model of the turbine field wheel

at a power of

$$L = \eta/27 \,.\, v^3 \,.\, F. \qquad [4]$$

The efficiency, η, is determined by the losses arising in the turbine itself as well as in the generator. Purely aerodynamic investigations as well as experiments with power-generating turbines, have been performed on this matter. Presentation of them is reserved for a special publication. The efficiency depends on the number and design of the vanes, on the wind velocity, on the operating speed, and on friction and current losses. High-speed systems have small, lighter vanes. The slow-running turbine carries a greater load and starts more easily.

For a given vane design, depending on the modulus U/v (peripheral velocity/wind velocity), U is the same for all diameters. Thus, the large turbines of the high wind power plant have low rotational speeds in spite of being high-speed systems, with large torques. Transfer of high powers at low rotational speed leads to oversized and uneconomical gears. Therefore, the mechanical power transfer which is common for windmills and smaller wind wheels is not applicable for slow-running large turbines. Utilization of the high peripheral speed of the large turbines led to development of the counter-rotating turbines, having vanes connected with large-diameter rings. The rings serve for direct power generation and are, therefore, designed as hollow bodies with closed outer walls. On one side of their interior they have the yoke ring and field, with the armature and armature coils on the other side. The rings and vanes are matched statically to each other for best results. It is important that the rings and vanes run elastically in parallel /503 so that they have no reciprocal movement in the direction of the axle under the effect of centrifugal force, temperature and other effects. As a result, a relatively small air gap can be allowable at very large diameters for the ring generators. Figure 4 shows a model of a turbine wheel with the field ring,

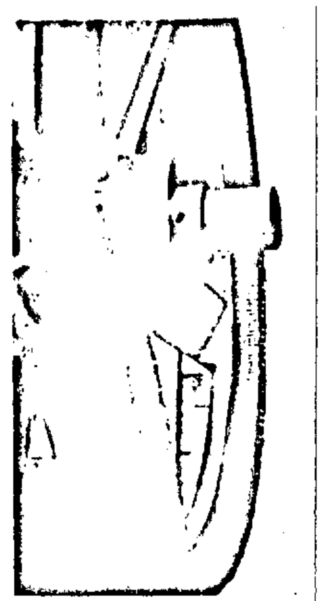

Figure 5. Model of the turbine armature wheel

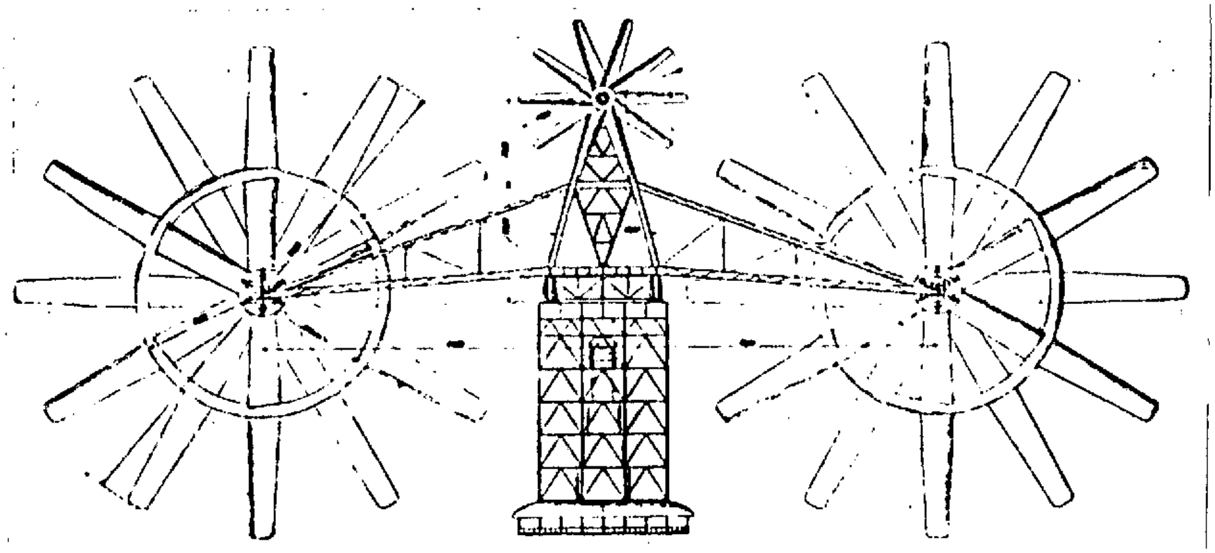

Figure 6. Arrangement of the wind wheels

and Figure 5 shows the second wheel with the armature coils. The exciter current is led through the vanes to the field coils by means of slip rings at the turbine hub. Special small, fast-running turbines with directly coupled counter-rotating direct current machines serve to generate the exciter current. Figure 6 shows the arrangement of the wind wheels. Figure 7 shows the system for generation of the exciter current. The three-phase current which is produced goes through the vanes of the other wheel to the second set of slip rings at the wheel hum. Figure 8, which presents a longitudinal section through the turbine axis, shows the arrangement for power transfer. The slip rings with the carbon brushes are safe from weather, protected, and well controlled between the wheels on the turbine axis. Each turbine hub has two bearing rings, each made up of 6 wheels of 4 steel rollers in self-aligning bearings. Between the wheel

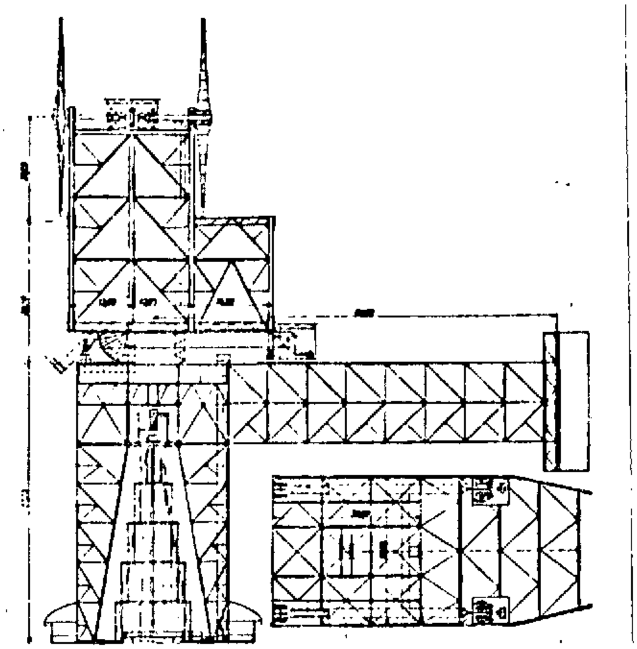

Figure 7. Turbine to generate the exciter current

rings there are tangential wheel guides which transfer the axial thrust from the turbine to the solid axis of the support frame.

With the low rotational rates, the large diameter of the ring generator leads to a multipole machine, the details of which can be seen in Figure 9. The air gap, cover guide, and ventilation can be seen in this figure. The armature coils are supported on insulators. The air flow through is left free with weather protection. The length of the armature is small, so that the cost of iron is small. Fittings which would produce turbulence are avoided. It is possible to pass through the hollow body of the rings, so that all parts are accessible. Installation or removal of individual coils is not difficult. The exciter leads, and the current takeoff, are in the hollow

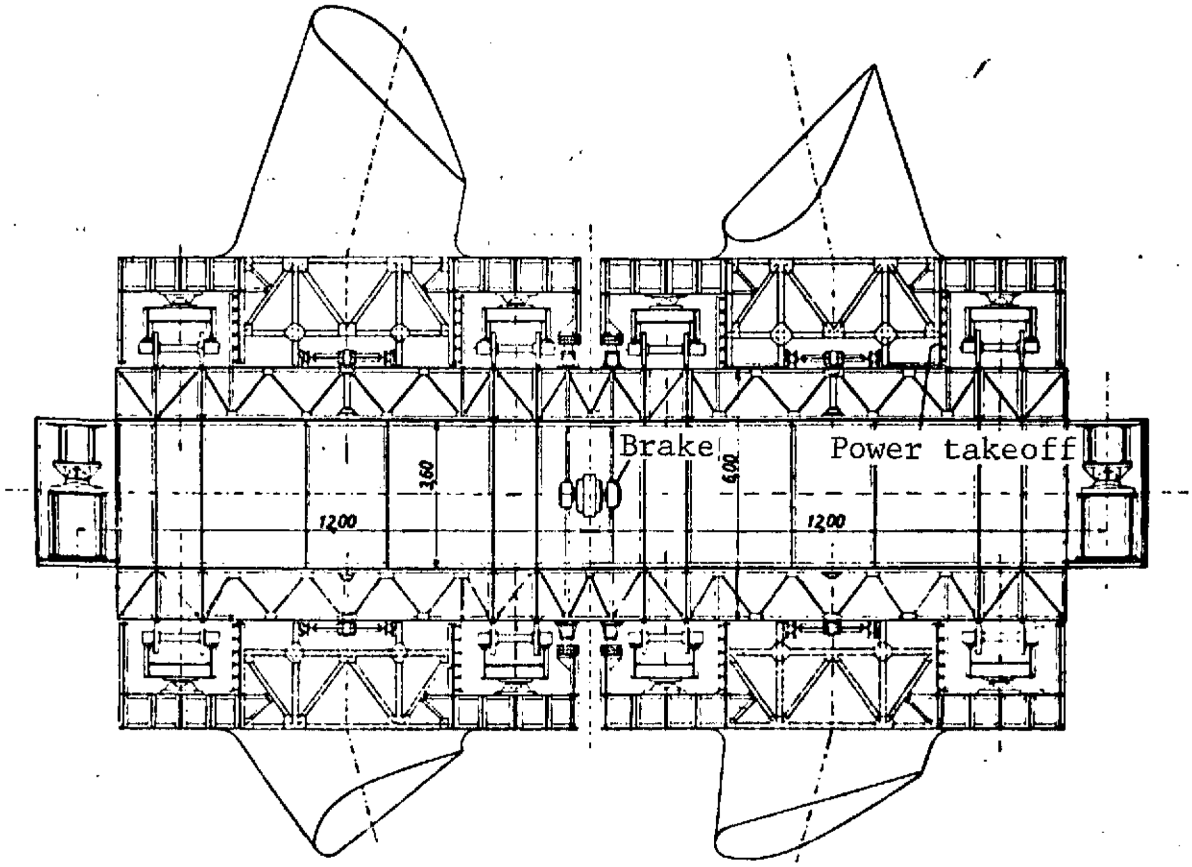

Figure 8. Longitudinal section through the turbine axis

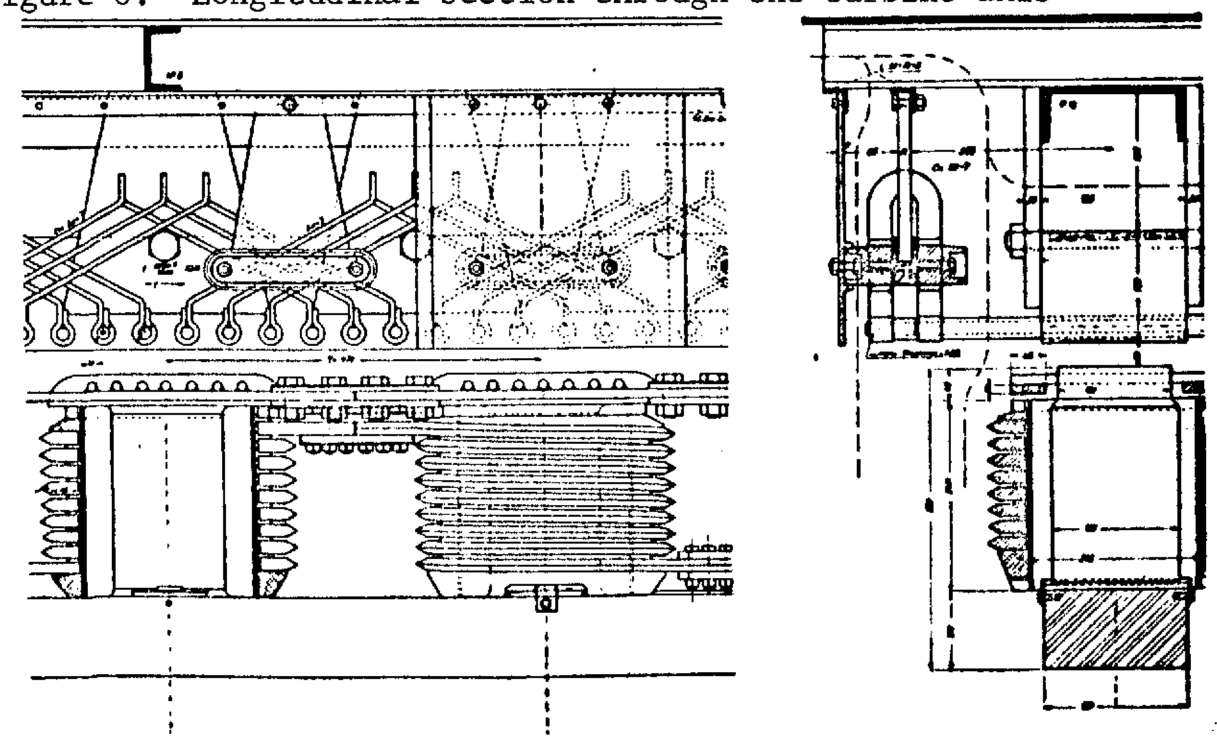

Figure 9. Details of a 20,000 kW generator field and armature winding

* Translator's note: Words in figure illegible.

structures of the vanes, which are likewise accessible. The three-phase current, generated at 5,000 to 6,000 volts, can be matched to the frequency of the consumer line in the well-known manner through control transformers and an intermediate direct current circuit. It is convenient to make the winding multiphasic so as to obatin smaller harmonics in the rectification. Excessive rotational speeds and powers are avoided by pivoting the whole turbine sideways before strong winds. The pivoting begins at v = 15 m/s. The thrusts and rotational rates are regulated by the oblique position. Figure 10 shows the curve for the power generated, which still increases at constant axial thrust and increasing v. At a tilt of 36° from the vertical, further increase of power with rising v is prevented. If the wind becomes a storm, an oblique position of 35° to 40° is sufficient to avoid overloads (Figure 11). In order to eliminate

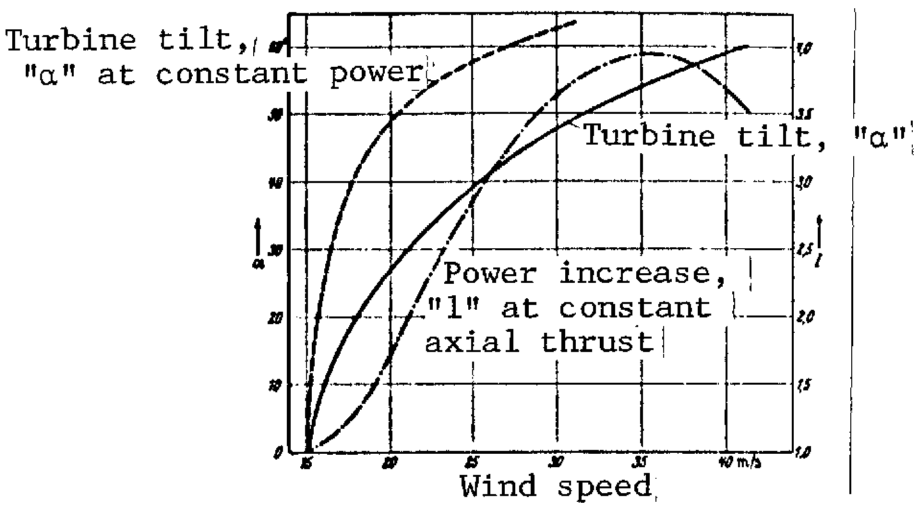

Figure 10. Increase in power with rising wind speed up to v = 15 m/s and the power curve with controlled constant horizontal thrust

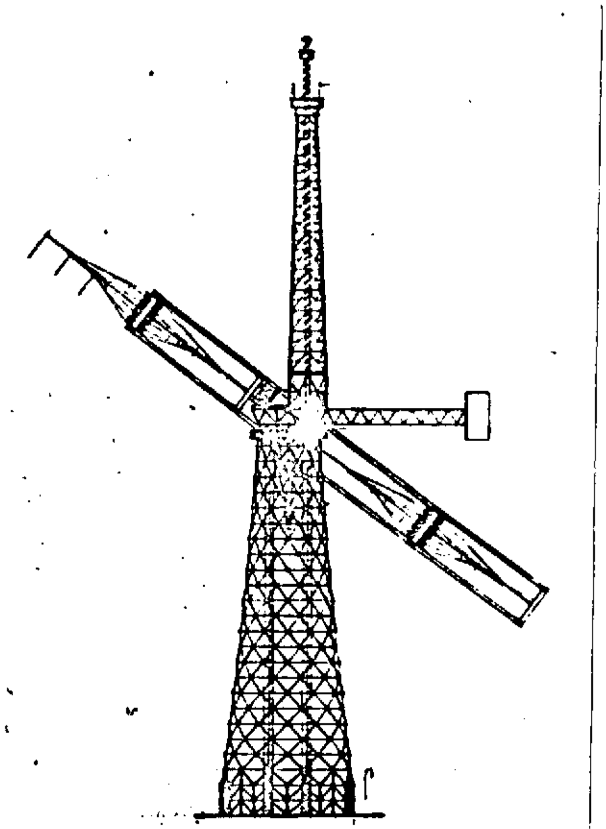

Figure 11. High wind power plant in the storm position

the power increase appearing between v = 15 m/s and v = 36 m/s, one does not maintain the turbine thrust constant, but reduces it above v = 15 m/s. The auxiliary turbines also take part in the tilting movements, so that the excitation is matched to the requirement of the three-phase generators. The behavior of the turbine wheels on sudden loss of load or short circuit was also studied. It was established that the rotational rates, which differ but little for the two wheels, will increase by at most 70%. Favorable static relations also appear for the full-scale design, which also ensures advantageous utilization of material for the generator. / 505

C. The Tower Construction

It is not well known that Germany has a free-standing steel tower which does not quite reach the height of the Eiffel tower, now 50 years old, but which can take up greater forces with considerably lighter design. Experiences in the design of this and other towers led to development of new tower designs. The new type of design is safe against torsion and offers minimum surfaces to attack by wind. In order to remove the turbines from the effect of the surface turbulence zone, the tower becomes about 300 m high. The width at the foot is then about 100 m, so that the maximum stiffness and smallest fluctuation is ensured at a slenderness of 1:3. The stability is so great that anchors would not be necessary. The natural vibration produces no resonance, even if other generators, of military type, for instance, load the tower along with the turbines.

At a height of 300 m, the structure is made up of 25 sections, each 12 m high. Each section is made of 12 or more triangles standing vertically, their points each bearing the feet of the triangles on top of them. In this way, we obtain a tapering toward the top with vertical wall sections, matching the stress on the girders to the course of the major forces. The vertical loads distribute themselves evenly over all the girders. The wind load is such that all the sections are utilized at the same time. The top of the tower has a width of 50 to 60 m, and is surrounded by a strong steel ring. A cone, which holds a rotatable structure, is suspended under the ring. The rotatable part is provided with a steering fin at the back, and at the top it has a bearing platform supporting the mounting frame with the turbines. The frame sits on strong roller bearings (Figure 6). It is convenient to use tubular steel bodies for the main load elements of the fixed part of the tower. This does not exclude the possibility of using wood for lower-power high wind power plants

(Figure 7). The mounting is designed so that the turbines can first be assembled on flat ground and connected to the support frames. Then derricks are used to lift the head with the turbines in the horizontal position. The tower is built underneath, in sections, with continuous change of support points. The cost of the derricks is balanced by the saving in construction time.

D. Storm Safety

In the Central European high altitude zone, wind speeds up to 50 m/s can occur, and up to 60 m/s in other parts of the earth. According to the well-known specifications, we apply a wind pressure of 250 kg/m^2, for which the steel structure, the foundation, and the stability are designed. The turbines should also work with their highest power in a storm, but this should be limited to the installed power for $v = 15$ m/s, and should remain constant. As previously mentioned in Section B, the /506 turbines are set obliquely so that the oblique position is matched to the increasing wind velocity. This is to avoid an increase in the power, in the axial thrust, and in the rotational speed. Pivoting down by 35° to 40° is sufficient, and this can, therefore, be done in a short period. On pivoting down, the roller bearings move against the wind. The center of effort of all wind areas for the support frame and the turbines is somewhat below the bearing surface of the roller bearing. The center of gravity for the vertical load is somewhat behind the support point. Up to $v = 15$ m/s, the tilting moment of the wind and the righting moment of the vertical loads are balanced. At higher wind velocity, the tilting moment increases and the wind attempts to tilt the turbines with supports and roller bearings. This is controlled by tackle, which is controlled by special wind meters through relays, which guide the roller bearings reliably. In order to start the acceleration of the masses on tilting, a cylinder with a long pressure cylinder is provided. It remains in the oblique position after tilting, and prevents the masses from swinging back.

Because of the previously described measures, only two static loads come into question for the axial thrust of the turbines: thrust corresponding to full storm load on the vane surfaces at a standstill, and that during work at $v = 15$ m/s, which is held constant at larger v by oblique positioning. The highest values are entered for the pressure on frames and other structures.

In the static treatment of the turbines, we must also consider the additional forces from bending, centrifugal force, gyroscopic action, the mass effect, and the electrical field [5].

The movement of the roller bearing against the wind results in a strong unloading of the tower, linked with an increase in stability. The upper movable loads are moved forward, and act against the tilting moment of the wind pressure, as can be seen from Figure 11. The pivoting of the turbines against the wind, therefore, is a very effective measure for the safety of the wind power plant in a storm.

E. Power Cost

On the basis of the current prices for large steel structures, reinforced concrete, and electrical equipment, we can establish extensive cost calculations for high wind power plants. Depending on the power and the construction site, the costs per kilowatt of installed power are from 260 to 340 Reichsmarks. The cost, K, per kilowatt-hour generally appear from the formula

$$K = \frac{A.(Z+U)}{t} + b,$$

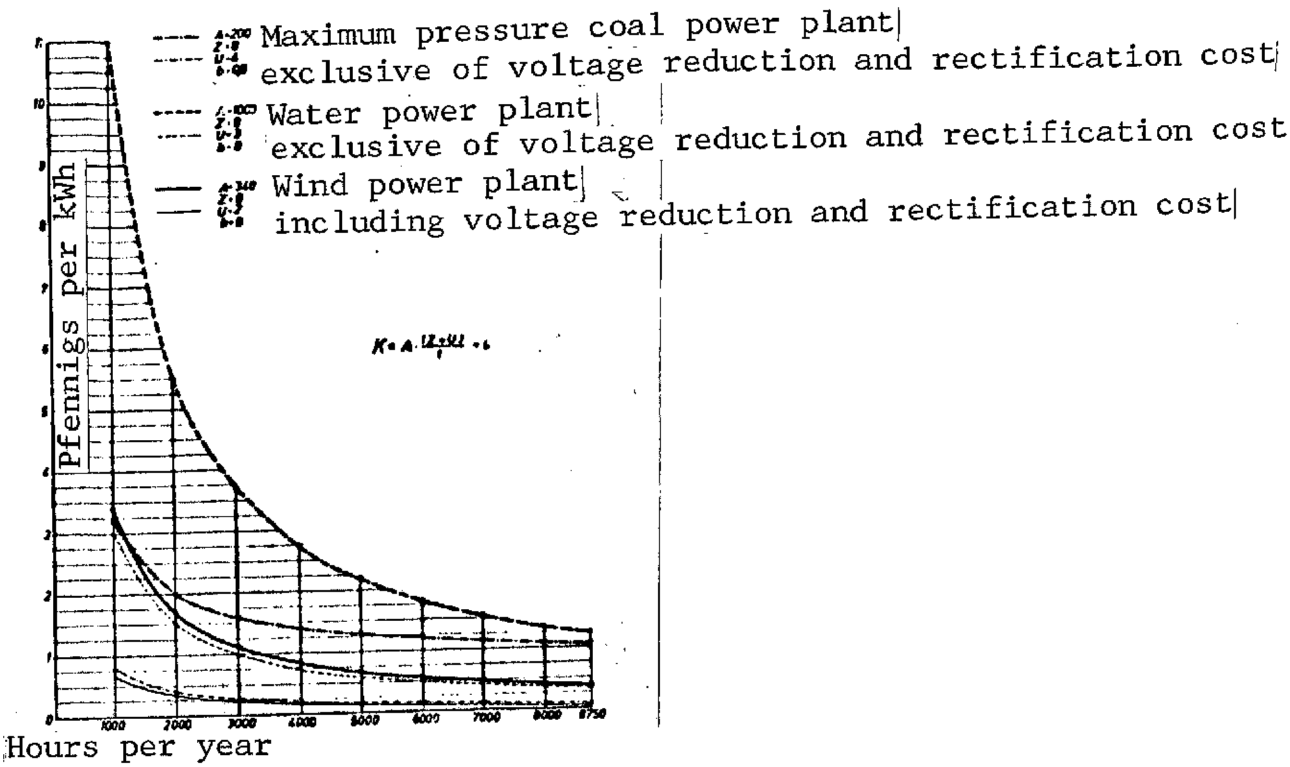

Figure 12. Comparison of power cost for the high wind power plant with other types of power plants. (The thin lines indicate the cost, U)

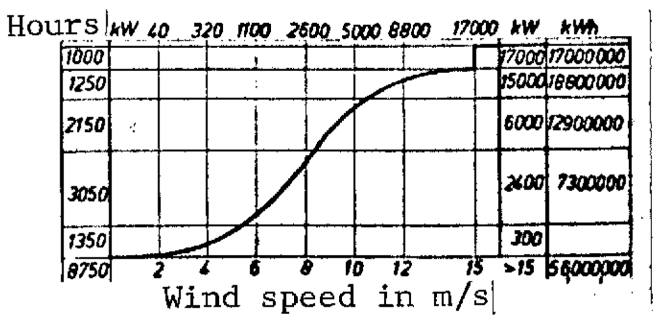

Figure 13. Annual power production for turbines with diameters of 160 m

in which:

A = cost per kilowatt of installed power

Z = interest

U = maintenance and operating cost

b = power cost

t = period of use of the installed power.

We also determine the costs, K, for coal and water power plants by way of comparison. We assume that:

Wind power plants:
A = 340 Reichsmarks/kW; Z = 8%; U = 2%; b = 0
Coal power plants:
A = 200 Reichsmarks/kW; Z = 8%; U = 4%; b = 0.8
Water power plants:
A = 1,000 Reichsmarks/kW; Z = 8%; U = 3%; b = 0.

Comparison of the power costs, according to Figure 12, shows a great superiority for the high wind power plant. With respect to water power plants, this superiority also extends to the annual power (Figure 13) and smaller system costs.

Summary

With appropriate design, high wind power plants using the high wind flows compete with thermal and water power plants.

REFERENCES

1. Assmann, Die Winde in Deutschland (The Wind in Germany), F. Vieweg, Braunschweig, 1910.

2, Hellmann, Sitzungsbericht' der Akademie det Wissenschaften (Meeting Report of the Academy of Sciences), Berlin 1914, 1917 and 1919.

3. Honnef, H. Windkraftwerke (Wind Power Plants), F. Vieweg, Braunschweig, 1932, p. 12.

4. Honnef, H. l. c., pp. 34 - 36.

5. See H. Honnef, l. c., p. 61.

Translated for National Aeronautics and Space Administration under contract No. NASw 2483, by SCITRAN, P.O. Box 5456, Santa Barbara, California, 93108